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Operational Concept Document For The Manufacturing Optimization (MO) System

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Raytheon Company

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13. ABSTRACT *(Maximum 200 words)*

This is the Operational Concept Document (OCD) that describes the mission of the Manufacturing Optimization (MO) System and its operational and support environments. The purpose of the Manufacturing Optimization (MO) system is to enable each manufacturing specialist to participate in the product/process development activity concurrently. The system will consist of a set of tools to model the manufacturing processes and centralize the various process tradeoffs. Recommendations can be compared and negotiated among the manufacturing participants. After the manufacturing team has consolidated their position, the results are passed back to the cross functional (top level) team for negotiation. The system will consist of the following five modules: process analysis, yield/rework modeler, cost estimator, guidelines, and manufacturing advisor, as well as, the integration of current DICE tools.

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Contents

Figures

1. Scope

1.1 Identification

This Operational Concept Document (OCD) describes the mission of the Manufacturing Optimization (MO) System and its operational and support environments. It also describes the functions and characteristics of the software modules within the overall MO system. The development activities are to be performed under Defense Advanced Research Projects Agency (DARPA) funding, contract number MDA972-92-C-0020, by the MO Development Team which is made up of personnel from Computer Aided Engineering Operations (CAEO) of the Raytheon Missile Systems Laboratories (MSL) with participation from the Mechanical Engineering Laboratory (MEL) and the Missile Systems Division (MSD) West Andover Manufacturing facility.

1.2 Purpose

DICE developed a concurrent engineering model that replicated the human tiger team concept. The basic tenet of the human tiger team is to have the various specialists contributing to the project co-located. In today's environment of complex product designs and geographically dispersed specialists, DICE envisioned a "virtual tiger team" working on a "unified product model" accessible by computer networks. Such an environment must enable the specialist from each functional area to work on the design concurrently and share development ideas. Raytheon proposed a conceptual refinement to the original DICE virtual tiger team. This refinement is a two level approach with a product virtual team having a global view supported by information supplied by lower level "specialized" process virtual teams. See Figure 1-1. This refinement is needed because of the growing complexity of our products, and supporting development processes make it difficult to have one representative adequately support a manufacturing position. The "virtual process team" concept would enable representation from each specialized process area.

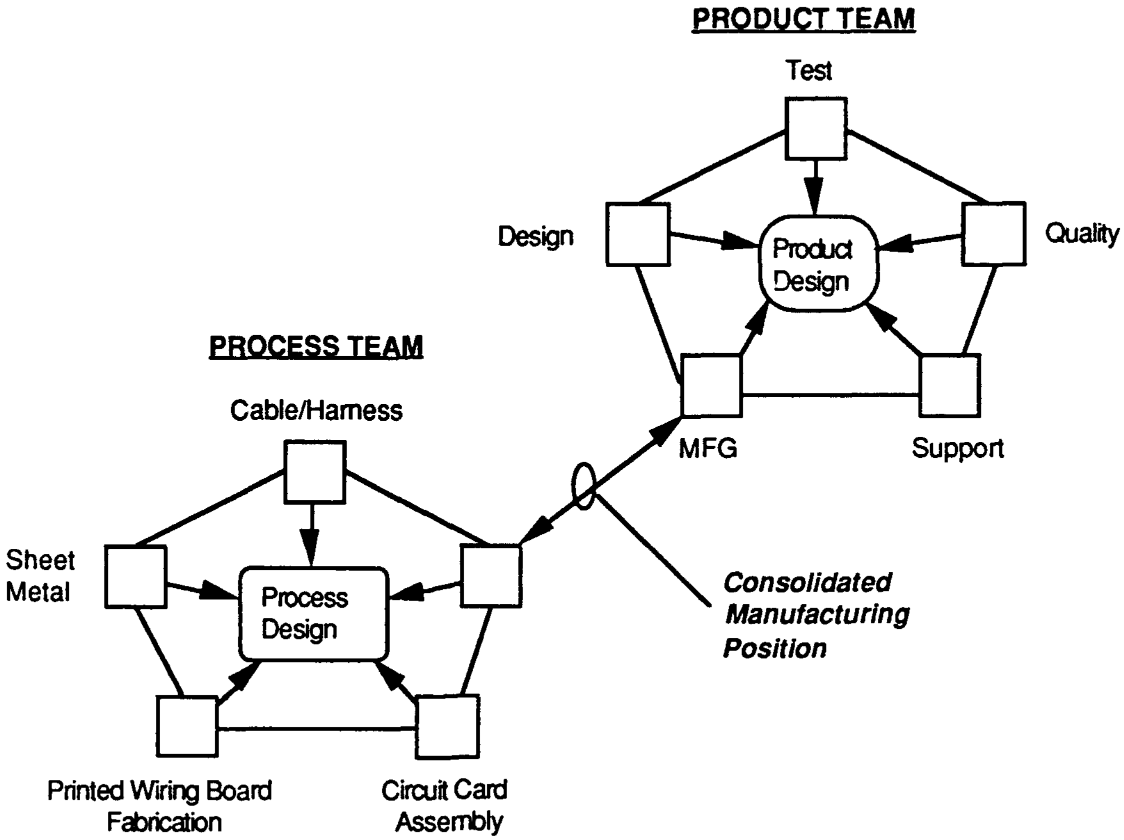

Figure 1-1. Two Level Team Concept

The purpose of the Manufacturing Optimization (MO) system is to enable each manufacturing specialist to participate in the product/process development activity concurrently. The system consists of a set of tools to model the manufacturing processes and centralize the various process tradeoffs. Recommendations can be compared and negotiated among the individual manufacturing participants. After the manufacturing team has reached a consolidated position, the results are passed back to the cross functional (top level) team for their negotiation.

1.3 Introduction

The purpose of this document is to provide the operational concept for the Manufacturing Optimization (MO) System. It contains the mission of the MO system, and its functions and characteristics.

2. Mission

2.1 Mission Need Requirements

In today's environment of complex product designs and geographically dispersed specialists, DICE envisioned a "virtual tiger team" working on a "unified product model" accessible by computer networks. Such an environment must enable the specialist from each functional area to work on the design concurrently and share development ideas. The MO system is a conceptual refinement to the original DICE virtual tiger team concept. This refinement is to have a two level approach with a product virtual team having a global view supported by information supplied by lower level "specialized" process virtual teams. This refinement is needed because of the growing complexity of our products and supporting development processes make it difficult to have one representative adequately support a manufacturing position. The "virtual process team" concept would enable representation from all the process areas. The requirements were originally stated in the DARPA Initiative in Concurrent Engineering (DICE) Manufacturing Optimization Volume I - Technical (reference 1).

2.2 Primary Mission

The DICE program is interested in new research and development of enabling technologies in Design for Manufacturing and Assembly (DFMA). The purpose of design for manufacture and assembly is to get early insight into the manufacturing requirements and cost of a new design. Manufacturability analysis must be performed early to have a significant impact on design. However, the ability to perform a meaningful analysis early in the design cycle is often affected by the product type. For instance, early on in the design of a PWB the form factor is established. This usually sets the overall dimensions of the PWB. From the overall dimensions, the maximum number of layers can be determined. By employing rule-of-thumb estimates about the design rules (trace width, pad sizes etc.) we can estimate the overall cost and manufacturability of the PWB, but this is just a first level of analysis. Further in the design cycle, detailed schematics will be developed and components selected, each of these gives more information about the design and impacts the ultimate cost of the board. Therefore, we have to perform a manufacturing analysis numerous times throughout the design cycle, refining manufacturability analysis and comparing it to the original baseline. The timing of analysis varies according to product types and their attendant design cycles.

Raytheon proposed the MO system which will enable one or more engineers to perform manufacturability analyses, and merge and compare their results for an array of product types. The system incorporates manufacturability analysis tools that enables the individual engineer to perform an analysis, and a manufacturing advisor manager that will manage the individual analyses and provide recommended changes to the design to the product team. The primary mission of the system is in researching and developing a "generalized" DFMA environment capable of modelling diverse manufacturing processes. The technology may also be applicable to other engineering disciplines such as test and integrated logistics support. We proposed to use a test case from current Raytheon DoD contracts to validate the benefits of our approach.

2.3 Secondary Mission

The DICE program has sponsored other development efforts that enable concurrent engineering technology. The secondary mission of the MO system is to "user harden" existing concurrent engineering technology by applying existing DICE Tools to other technology areas, in this case Design for Manufacturing and Assembly (DFMA). The DICE tools proposed for use under the MO program included ROSE Database Management System (DBMS), Constraints Management System (CMS), and the Requirements Manager (RM). The Project Coordination Board (PCB) and Communications Manager (CM) were added to this list of candidate tools because the second release of the CMS will be integrated with the PCB/CM.

2.4 Operational Environment

The DICE program has been chartered with developing technology that enables concurrent engineering. Part of the DICE concurrent engineering model is a replication of the human tiger team concept that has been successfully used on small scale projects to bring high quality products to market quickly. The basic tenet of the human tiger team is to have the various specialists contributing to the project co-located.

The MO system will provide a conceptual refinement to the DICE virtual tiger team concept. In the present DICE virtual tiger team model, all functions are represented and linked concurrently to the product design at a single level. MO will provide a two level approach with a virtual product team having a global view supported by information supplied by the virtual process teams. The rationale for this refinement is based on the growing complexity of both the products and supporting development processes. It is increasingly difficult to have one representative adequately support a manufacturing (or logistics) position that involves numerous specialized process areas. In practice, the assigned representative is usually a specialist in one of the process areas and has only generalized knowledge about the other processes. The "virtual process team" would enable representation from all the process areas. The product team would concentrate on using the cost/yield information supplied by the process teams, and determine the best plan by taking into account the existence or implementation of manufacturing, logistics, or test plans. The product team would be responsible for decisions that span cross-functional expertise.

Ideally, the virtual process team is an extension of the product team. It will consist of specialists representing all the various processes. For instance, a process team for a complex electro-mechanical assembly might consist of a PWB Fabrication, Circuit Card Assembly, Cable/Wire Harness, and Sheet Metal representatives. They will have access to the unified product database and will be responsible for the manufacturing inputs to the product team. Each member of the process team will review the design, perform a DFMA analysis, and make design or process change recommendations. The product team will then negotiate with the process team to arrive at a position (and perhaps alternatives) consistent with the manufacturing plan.

The virtual process team will be supported by a set of tools that implements a concurrent DFMA system. These tools will enable the manufacturing process team to perform individual DFMA analyses, merge and review these analyses, and negotiate trade-offs among the processes. A consolidated report and recommendations is passed back to the product team. The MO system will be composed of five modules: process analysis, yield/rework modeler, cost estimator, guidelines, and manufacturing advisor, as well as, the integration of current DICE tools.

3. System Functions and Characteristics

3.1 System Functions

The MO system will consist of five software modules: process analysis, yield/rework modeler, cost estimator, guidelines, and manufacturing advisor, as well as, the integration of current DICE tools. The process analysis module performs the initial analysis on the design to determine the manufacturing process (a set of operations) required to produce the part. The yield/rework modeler calculates yield and rework values by performing a look up of design features versus an operation. The cost estimator module will calculate cost for each operation used to produce the part. The guidelines module captures design for manufacturing and assembly guidelines and associated recommendations. When guidelines are violated, the violation and the associated recommendation are recorded. The manufacturing advisor analyzes the data generated by the individual analyses and guides the negotiation/trade-off process by identifying major cost drivers and guideline violations. It recommends design alternatives based on the influence of the design parameters on the cost analysis. This module will produce the output of the sub-team that gets passed to the top level team.

Based on the preliminary evaluation of the DICE tools, three were proposed for incorporation into the MO system, ROSE Database Management System (DBMS), Constraint Management System (CMS), and Requirements Manager (RM). The original scope of the project was expanded to include the Project Coordination Board (PCB) and Communications Manager (CM) because the second release of the CMS will be integrated with the PCB/CM. The proposed use of ROSE is to store and manage the process models, Constraint Manager to constrain the product design to process capabilities, and Requirements Manager to manage guidelines. The Project Coordination Board (PCB) and the Communications Manager (CM) were reviewed in conjunction with the CMS. The DICE MO architecture is shown in Figure 3-1.

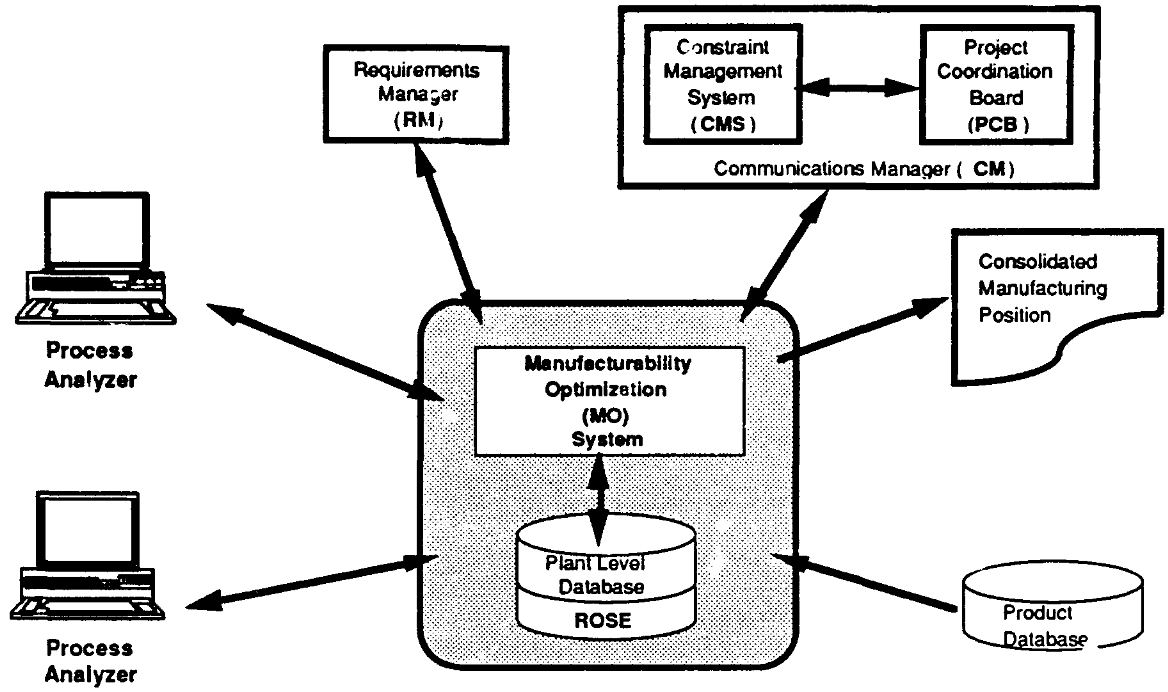

Figure 3-1. Proposed DICE MO Architecture

3.1.1 Process Analysis

The process analysis module performs the initial analysis on the design to determine the manufacturing process (a set of operations) required to produce the part. This module will take a knowledge based approach that will compare design features and attributes against process capabilities to determine a part's process sequence. The actual process will be characterized as a process logic tree representation and selection algorithm where the cost can be based on the process. This representation will provide the ability to focus in on cost drivers. The system will also have the ability to store alternative models of a particular process. This capability will provide the process engineer a means of exploring alternative process approaches and plan process improvements. The ROSE DBMS will be used to store the data associated with the process logic, selection, and analysis results.

3.1.1.1 Process Logic Representation

The process logic representation will be modeled as a hybrid decision tree with rules attached to each node of the tree. The decision tree representation was selected because it allows the system to display the basic flow of the process in a presentation format similar to the manufacturing engineers flowcharts. The decision tree informs the user of the basic flow of the overall process while letting the user plan at various levels of abstraction. These levels include the process, operation, and operational step. The process is an organized group of manufacturing operations sharing characteristics, the operation is a common unit of work that is performed on the part, and the operational step is an elemental unit of work within an operation. By defining the levels as we have, a hierarchical planning strategy is enabled. Using this schema, we can consider alternative processes, plan the operation flow within the selected process, and then detail the individual steps of that operation, such as setup and run time elements.

3.1.1.2 Process Selection

The process selection is guided by the representation of the decision tree structure which sets the initial evaluation search order and the rule processing mechanisms. The rules are attached to individual nodes in the tree, and are used to evaluate the node. The purpose of the evaluation is to cause selection of the node. If a rule is evaluated as true then the search continues past that node to evaluate lower levels. As the tree is evaluated, the rules look at part characteristics and other node values (i.e. true or false), operations and operational steps are stored to form the process sequence. Each operation in the process sequence is then evaluated for labor standard content.

3.1.2 Yield/Rework Modeler

One of the major manufacturing cost drivers is production yields. Poor yields increase costs while tying up production capacity and other resources such as engineering support and materials. The yield/rework module will model yields on an operation by operation basis. Design feature values will be assigned contributing yield values. The yield/rework modeler will compute the yield of an operation based on the design features and contributing yields that affect that operation. This module calculates yield and rework values by performing a look up of design features versus an operation. If multiple features affect an operation then a composite value is computed based on defined relationships among the features.

3.1.3 Cost Estimator

This module will calculate cost for each operation used to produce the part. The individual operation cost will be calculated using labor standards, wage rates, and production efficiencies. Each operation cost will then be factored by yield and rework rates to arrive at an estimate.

3.1.4 Guidelines

This module captures design for manufacturing and assembly guidelines and associated recommendations based on quantitative and qualitative producibility issues. When guidelines are violated, the violation and the associated recommendation are recorded. The guidelines can be evaluated separately, or triggered based on the process analysis. Unlike the process selection constraints, the guideline violations may not cause alternative selection. The result could be an operation cost increase, for instance, the need for non-standard tooling, a yield drop, or a less tangible impact. Each guideline will be accompanied by a recommendation that would be presented through the manufacturing advisor. The manufacturing team will develop guidelines that will give the design team insight into the manufacturing requirements, and can be one source to initiate execution of manufacturability analysis. For example, if heavy ground planes are required, the preferred location is on center layers of multi-layer boards with outer layers symmetrically balanced. The reason for this manufacturing guideline is that non-symmetrical ground planes cause warping of the PWB as a result of temperature cycling. The copper ground plane expands at a rate different than the rest of the PWB and causes deformation.

3.1.5 Manufacturing Advisor

The manufacturing advisor analyzes the data generated by the individual analyses and guides the negotiation/trade-off process by identifying major cost drivers and guideline violations. It recommends design alternatives based on the influence of the design parameters on the cost analysis. The process routings, guideline violations and recommendations, and cost estimates will be organized such that the effects of each design feature can be reviewed across processes. The advisor organizes the data consolidated within ROSE and summarizes processes, guideline violations, and recommendations. The advisor will facilitate the comparison among the alternatives.

It will provide variance and sensitivity analyses on the cost estimates which will allow the team to look at the total cost variance caused by adopting various design alternatives. As each process runs its analysis on a set of design alternatives the cost estimates can be compared. This will show both the changes in cost of each process and the total change in product cost.

At least two output reports will be developed for the system. The first report will contain the data for an individual analysis, such as process sequence, yields, cost and violations/recommendations. The second report will summarize the analyses of each process team member and present a set of recommendations to be communicated to the top-level team.

3.1.6 Integration of DICE Tools

The DICE program has sponsored other development efforts that enable concurrent engineering technology. The secondary mission of the MO system is to "user harden" existing concurrent engineering technology by applying existing DICE Tools to other technology areas, in this case Design for Manufacturing and Assembly

(DFMA). The DICE tools proposed for use under the MO program included ROSE Database Management System (DBMS), Constraints Management System (CMS), and the Requirements Manager (RM). The Project Coordination Board (PCB) and Communications Manager (CM) were added to this list of candidate tools because the second release of the CMS will be integrated with the PCB/CM.

ROSE is an object-oriented database management system that has been developed for engineering applications and enhanced to support the DICE program. The ROSE Database Management System is a database that supports concurrency using a data model that allows the differences between two design versions to be computed as a delta file. ROSE will be used to store and manage the data files for the manufacturing processes and operations, as well as, the various analysis results. Its proposed use in the MO system is to store the process routing sequence which will enable us to do comparisons of process trade-offs via the delta files. The process database consists of the process selection knowledge base, process/operation data, yield/rework data, guidelines, and recommendations.

The Constraint Management System allows the user to build constraints into the concurrent engineering process. The system tracks constraints and can notify, or launch an evaluation when constraints are not satisfied. The CMS will be used to manage the constraints placed on the design by the capabilities of the process required by the MO system.

The Project Coordination Board (PCB) is a system being developed to provide support for the coordination of the product development activities in a cooperative environment. The PCB provides common visibility and change notification through the common workspace (*cw*), planning and scheduling of activities through the task structure, monitoring progress of product development through the product structure (i.e. constraints), and computer support for team structure through messages. The Communications Manager (CM) is a collection of modules that facilitates distributed computing in a heterogeneous network. It promotes the notion of a virtual network of resources which the project team members can exploit without any prior knowledge of the underlying physical network. The CM would be useful for those that would like to build transparent tools, virtual project networks, have access to remote tools, perform network tasks, perform message passing, and/or perform inter-process file transfers.

The Requirements Manager (RM) is a system designed to manage product requirements, specifications and corporate policies to support concurrent engineering. The system allows the users to define requirements for a project or incorporate standard requirements through pointers (file name). The system also tracks parties interested in specific requirements and provides notification capabilities upon modification to that requirement.

Status updates could include modifications of a requirement, product design driven violations of a requirement, or satisfaction of a requirement. The purpose of integrating the MO manufacturing guideline functionality into the RM is to give the "top level" product development team insight into the manufacturing requirements apart from the MO analyses. These manufacturability guidelines will be entered into the RM so that they are available to the product design team along with the other requirements place on the design.

For more details on how the DICE tools will be integrated into the MO system refer to the Description of CE Technology For The Manufacturing Optimization (MO) System document (reference 2).

3.2 Operator and User Interaction

The MO system will enable members of the manufacturing process team to analyze a design with respect to the process or speciality they are representing. The operational concept will be demonstrated using two manufacturing processes, printed wiring board fabrication and printed wiring board assembly. Within each domain, process alternatives will be explored as part of the test case demonstration. The project will assume the existence of CAD design data at the start.

Before an analysis can be run on a design, the process database must be populated. The manufacturing specialist will be provided with a set of utilities that will allow population of the database through addition, deletion, and/or modification of the various types of data. The process database consists of the process selection knowledge base, process/operation data, yield/rework data, cost data, guidelines, and recommendations. All data are managed through the ROSE system.

Once the process database is populated, evaluation of the design is possible. Evaluation starts with the process analysis module. This module executes the process knowledge base to select a process and establish the list of operations that will produce the part. After the operation sequence is determined, each applicable operation is evaluated to calculate yield and rework values. These values are established by the relationship between the design and the operation. The cost is calculated based on the labor standards associated with each operation which are factored by the yield and rework values. This method accounts for the cost of scrap and rework. These analysis results are stored in the ROSE DBMS.

The rules that determine the selection (or evaluation) of operations can be considered as a set of constraints. If the constraints are satisfied then the operation can produce the part or feature (based on scope of rule set). If the rules or constraints of the operation are not satisfied then the operation is not valid for use. By interfacing with the constraints manager, these process/operation rules can monitor the design and be informed when the design has exceeded process capabilities. This can function by informing the team that the current design is limiting process alternatives or that the initial process evaluated for the design is no longer valid and a re-evaluation must be performed. In this scenario the re-evaluation will result in a process change.

The guidelines can be evaluated separately, or triggered based on the process analysis. The guidelines delineate quantitative and qualitative producibility issues. For each issue, there is a related recommendation. These guidelines will also be managed by the Requirements Manager. Unlike the process selection constraints, the guideline violations may not cause alternative selection. The result could be an operation cost increase, for instance, the need for non-standard tooling, a yield drop, or a less tangible impact. Each guideline will be accompanied by a recommendation that would be presented through the manufacturing advisor.

Once each participating team member has run an analysis, the data is consolidated within ROSE through the manufacturing advisor. The advisor organizes the data by summarizing processes, guideline violations, and recommendations. From this summary, the process team members can identify major costs drivers and prioritize change recommendations. These recommendations could then be sent to the product team. The process team could also elect to re-run each analysis using the recommended changes to compare the costs of the proposed design with the original design.

Finally, since the manufacturing process models are stored in ROSE, the process team could explore changes in the processing approach, such as adding a larger capacity machine by utilizing the set of process database utilities, and then analyzing the effect on the design costs. Again, through the manufacturing advisor the comparison among alternatives is facilitated. The flow diagram of the MO system is shown in Figure 3-2.

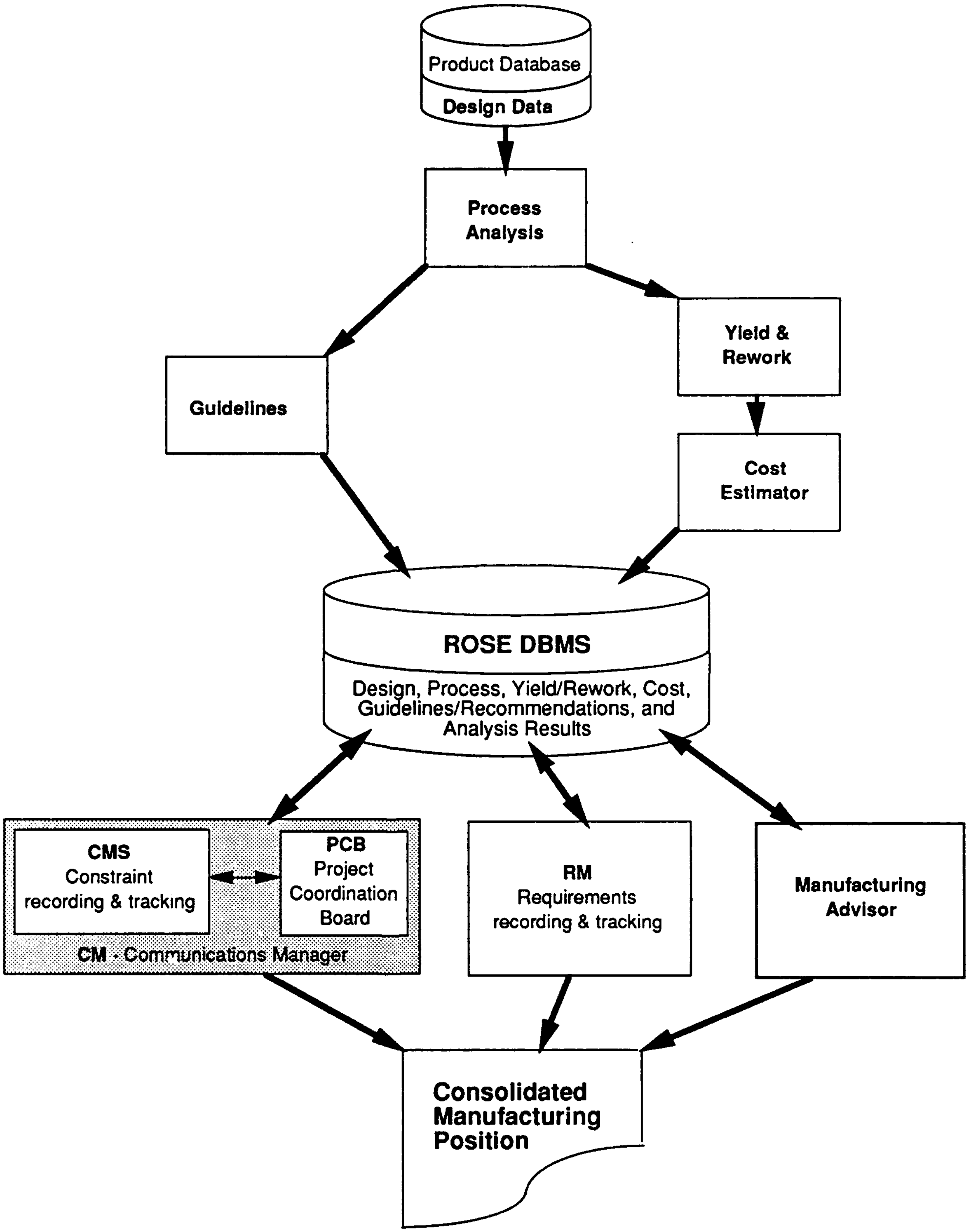

Figure 3-2. Flow Diagram of the MO System

3.3 Computer System Characteristics

The MO system will be developed on Sun SparcStations running the SUN UNIX Operating System V4.1.1. All source code will be written in the C++ programming language using SUN C++ V2.1, and all user interface code will be developed using OSF-Motif Libraries under the X Window Environment.

4. References

1. BR-20558-1, 14 June 1991, DARPA Initiative In Concurrent Engineering (DICE) Manufacturing Optimization - Volume I - Technical.

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7. User Manual for the Project Coordination Board of DICE, February 26, 1992, Contract No. MDA972-88-C-0047, CERC.

5. Notes

5.1 Acronyms

CAEO	Computer Aided Engineering Operations
CDRL	Contract Data Requirements List
CM	Communications Manager
CMS	Constraint Management System
DARPA	Defense Advanced Research Projects Agency
DBMS	Database Management System
DFMA	Design for Manufacturing and Assembly
DICE	DARPA Initiative In Concurrent Engineering
MEL	Mechanical Engineering Laboratory
MO	Manufacturing Optimization
MSD	Missile Systems Division
MSL	Missile Systems Laboratories
PCB	Project Coordination Board
OCD	Operational Concept Document
OSF	Open Software Foundation
PWB	Printed Wiring Board
RM	Requirements Manager

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